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Patents Act 1990

Neopraxis Pty Ltd

PROVISIONAL SPECIFICATION

Invention Title:

Motion Monitoring and Analysis System

The invention is described in the following statement:

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Motion Monitoring and Analysis System

Field of the Invention

The present invention relates to a system for analysing, monitoring and recording the motion of a number of moving parts of a body performing a task. In particular, the present invention relates to a system for analysing, monitoring, and recording the motion of a human body during acute and chronic lifting tasks.

Background of the Invention

Work place related injuries and in particular, back injuries, are significant problems in many industrialized countries. Such injuries are costly to a country's economy in terms of treatment for the injury as well as the loss of productivity that such injuries bring to the workplace.

For instance, in Australia, there are approximately 500,000 reported workplace related injuries reported each year, of which 25% are injuries to the lower back. In Queensland alone, it is estimated that injuries relating to manual handling, which are typically related to the condition referred to as low back disorder (LBD) , resulted in the loss of over 40,000 workdays. Equally, in the United States it is estimated that costs associated with back injuries alone easily exceed US$40 billon. As such, many companies are finding that more and more of their expenses are being channelled into workers compensation payments and associated insurance than has traditionally been the case. In this regard, there is no surprise that conditions such as LBD have been identified as a major work place health and safety issue.

In order to address this important issue there is a need to investigate and evaluate factors associated with the mechanics of motion, such as lifting, that are shown to increase the incidence of work place injuries such as LBD. It is considered that by quantifying such factors, it may be possible to lower the risk of injury to the worker.

In this regard, various methodologies exist that analyse lifting tasks in order to quantify LBD risks, such as the National Institute for Occupational Safety and Health (NIOSH), Static Strength Prediction Program (SSPP), Lumbar Motion Monitor Program (LMMP) and United Auto Workers-General Motors Ergonomic Risk Factor Check List (UAW-GM RFC). Whilst each of these methodologies take a slightly different approach to assess LBD risk, they all take in to account common factors such as weights lifted, starting heights, reach distances and posture.

The NIOSH equation is perhaps the most well known of these methodologies and is designed as a paper and pencil assessment tool for ergonomists or workplace assessment officers providing an empirical method for computing a weight limit for manual lifting. This limit has proven useful in identifying certain lifting jobs that posed a risk to the musculoskeletal system for developing lifting related low back pain.

One system for applying the NIOSH equation is described in US Patent No. 5,621,667. This patent describes an instrumented analysis system based on a retractable cable and potentiometer system which can determine the NIOSH equation multipliers indicative of physical parameters related to a lifting task under analysis. However, the instrumented system described is a rather dedicated system and is cumbersome and not easily implemented in a normal working environment. Further such a system will not allow unimpeded long term, analysis of the lifting task during the entire workday. In this regard, the system requires a dedicated space to set up the instrumentation and experienced personnel to operate the system and as such is better suited to a laboratory environment than a regular work environment.

Typically, there are very limited facilities to perform monitoring and analysis of factors associated with tasks such as lifting within the actual work environment. Workplace assessment as it pertains to LBD can only monitor motion for acute periods of time or use equipment that is cumbersome to use in a regular work environment over prolonged periods of time, and takes time to analyse. In addition most of the workplace assessment tools, contain measurement of some subjective components which are difficult to accurately

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and reliably assess and are usually dependent on the experience of the assessor taking such measurements.

Whilst more detailed motion analysis can be achieved in laboratory settings using laboratory-based equipment such as video motion analysis systems, these systems are expensive to construct and operate, and access to such facilities is typically restricted with there being only approximately 200 such facilities worldwide. In addition, laboratory analysis sessions require simulated work environments which in reality to not reflect the real work situation. In addition these facilities are only able to monitor motion in the laboratory setting for a short period of time during which a subject is being studied in the laboratory, and the ability to monitor motion over a longer period of time and in everyday work place and conditions, is not possible.

Therefore, the ability to monitor and analyse overall motion in the industrial or workplace setting, provides the opportunity to identify aspects of the overall movement that affect the functionality of the overall movement. When applied to human motion in the industrial or workplace setting, it may be possible to identify specific patterns of movement which increase the risk to worker injury, be it lifting or other repetitive movements. This may be particularly important for those involved in assessing workplace safety, such as ergonomists, workplace safety consultants, and health professionals who may wish to analyse the work environment including the motion of the worker within the environment in great detail so as to minimise injury and ensure maximum safety and optimise workplace efficiency. Equally, individuals may also wish to analyse motion of those who need to be trained to perform a particular task (i.e. lifting) in detail to ensure minimization of injury risk and to assess where help is needed.

In order to enable greater access to devices that can monitor human motion in the work environment through out the day, a need therefore exists for a motion analysis system, which is low in initial cost, reliable, robust, simple and low cost to operate. Ideally such a system could be worn in the work environment by a subject/worker for extended periods allowing motion data to be collected under actual working conditions as the subject goes about their work activities.

In particular, such a system would make workplace analysis far more widely available for those individuals requiring such careful work place monitoring and assessment incorporating many of the common assessment tools (including but not restricted to NIOSH, LMMP, SSPP, UAW-GM RFC or future assessment tool). In addition, the applications of such a system would be far broader. For example, such a system could be used to analyse real-time motions associated for training, modelling, real time monitoring, incorporation of physiological measures, work redesign and general injury prevention.

Summary of the Invention

The present invention resides in a motion analysis and monitoring system for monitoring the lifting motion of a subject, the system comprising: a plurality of sensor elements mounted to movable body segments of a subject, said sensor elements capable of sensing parameters associated with individual movement of the body segments; a control device for receiving said sensing parameters from said sensor elements and combining said sensing parameters to determine overall lifting motion of said subject; and an analysis means for analysing said overall lifting motion of said subject to determine whether said overall lifting motion of said subject is within acceptable limits.

Preferably, the sensor element includes a data memory and microprocessor for storing and processing said sensed parameters of movement prior to sending to the control device for analysis.

Preferably, each sensor element includes gyroscopes and accelerometers for measuring angular velocity of the movable part of the movable body segment in at least one or more planes of motion and for measuring acceleration components in three dimensions. More preferably, each sensor element monitors angular velocities in the sagittal, coronal and transverse planes of the body segment that the particular sensor element is mounted on and monitors linear acceleration experienced in three dimensions in relation to the body segment to which it is attached.

Preferably, each sensor element may also monitor the sagittal, coronal and relative transverse angles of its associated body segment and measure pressures as a resistance measurement from pressure sensors provided with the system. Further, each sensor element may also measure strain via strain gauges provided with the sensor element. The sensor also preferably has the provision to accept external signals from other devices such as, but not restricted to heart rate monitors, other physiological measurement devices, instrumented shoes (for example, pressure distribution systems) and fixed force plates.

Preferably, the control device is in communication with the sensor elements for controlling and collecting data from the sensor elements, and for analysing, providing real time feedback (aural and/or visual) and displaying the data. Preferably, the control device is in the form of a hand-held programmable device such as a pocket PC, PDA or mobile telephone-PDA combination. The control device could also be a personal computer (PC). Additional control devices can also be embedded within a sensor unit.

To facilitate operation of the external control device, the control device preferably has a display screen. The display screen may be a liquid crystal display (LCD) that may be used for controlling the operation of the system. Further, the LCD may be used by an operator for analysis and display of the motion data obtained by the motion analysis system. The external control device can also be used to program the embedded sensor control device in order to perform general and specific function via hardwire or wireless communication protocols.

The control device is preferably either placed external to a sensor or embedded within a sensor may include a memory card slot such as a flash memory card slot. Note that a memory card can be also embedded within a sensor. Accordingly, the interface unit for the external control device may include a flash memory interface card which interfaces to the control device via a compact flash bus.

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Still further, the control device may preferably include a remote control facility that enables the operator to interact with the system remotely without the need for physically operating the controller. Preferably, the remote control unit provides the clinician with a non-visual confirmation of communication of data from the remote control unit to the controller.

The interface unit of the controller may preferably include a remote control interface. This may be a bi-directional communications interface between the remote control unit and the controller. Also, this communications interface may be a wireless interface so as to minimise the necessity for fitment of cables and removing the possibility of cables becoming entangled or dislodged.

Preferably, the analysis means is a software program that is stored on said control device or said remote control facility. Said analysis means capable of comparing the parameters associated with the overall lifting motion with the parameters associated with a lifting motion within safe and accepted limits and indicating whether the overall motion of the subject is within said safe and accepted limits.

Brief description of the drawings

The invention is now described by way of example with reference to the accompanying diagrammatic drawings in which:

Figure 1 shows the motion monitoring and analysis system of the present invention for monitoring the lifting motion of a subject;

Figure 2 shows a software screen associated with the present invention that collects and displays anthropometrical data of measurements taken by the present invention;

Figure 3 shows an interactive frame-by-frame analysis screen of the present invention with an animated version of the sensed motion; and

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Figure 4 shows the parameter result screen of the NIOSH analyser of the present invention.

Detailed description of the invention

The motion monitoring and analysis system of the present invention is generally referred to by reference numeral 10 in Fig. 1.

The system 10 includes a plurality of sensor elements 20 removably attached to segments of the body which require monitoring. Each of the sensor elements 20 are provided with associated componentry and circuitry to measure, process and store motion data of the body segment upon which it is placed. Each of the sensor elements 20 communicates with a controller 30 via a wired (not shown) or wireless connection to fed the motion data obtained by the sensor elements for further processing. The controller 30 is a body worn or carried device which can further communicate with a remote control device 40, such as a remotely positioned personal computer. The remote control device 40 thereby providing remote access to the data collected and stored by the system 10.

Each of the sensor elements 20 consist of a small light weight casing and typically weigh less than 22 grams. The sensor elements are typically made from a plastic housing having a substantially rectangular shape having a length of 65mm and a width of 34 mm and a thickness of 12 mm. The dimensions of the sensor elements 20 are sufficient to house a gyroscope and one or more accelerometers as well as appropriate circuitry to store the data collected. Each sensor element 20 is capable of measuring angular velocity of the body segment in at least one or more planes of motion, measuring acceleration components in three dimensions and measuring outputs from pressure sensors 50 and strain gauges 60 or three pressure sensors alone for determining positional information of the lower extremities, upper extremities, torso and head of the subject's body. More particularly, each sensor element 20 monitors angular velocity in the sagittal plane of the body segment that the particular sensor element 20 is mounted on. Further, the sensor element 20 monitors linear acceleration experienced in three dimensions in relation to the body segment to which it is attached. Each sensor element 20 can also monitor the

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sagittal, coronal and relative transverse angles of its associated body segment and measures pressures as a resistance measurement from the/or each pressure sensor 50. Each sensor element 20 can also measure strain via its strain gauge. Finally, each sensor element 20 may accept signal inputs from peripheral devices such as, simple pressure sensitive transducers (i.e. on-off switches), heart rate monitors, foot pressure distribution systems, global positioning sensors, portable gas analysis systems or other devices in order to incorporate this information with body movement.

The data collected by each sensor element 20 may be either stored in the sensor data memory and downloaded to the controller 30 at a designated time delay following data collection or collected in real time by the controller 30. In this regard, the controller 30 constantly receives the information from each sensor element 20 during the motion.

In a preferred embodiment, each sensor element may also contain their own embedded and programmable control unit and also a memory unit without the need for an external control device. Such an arrangement allows multiple sensors to operate independently in a distributed fashion wherein motion data can be downloaded for analysis at a later time. In such an embodiment, each independent sensor has a timing device, which can be synchronised to other sensors so that all data from multiple sensors can be fully synchronised. The sensor can also be connected to other sensors and an external control unit using wireless communication, such as, but not limited to "bluetooth" technology.

In a system where lift task monitoring is desired, it will be appreciated that, in respect each of the lower extremities, the relative positions of the thigh (the part of the lower extremity between the hip and knee), leg (the part of the lower extremity between the knee and ankle) and arms (the part between the forearm and upper arm) relative to each other and the torso need to be monitored. Accordingly, each upper and lower extremity may use at least six sensor elements 20, one mounted on the thigh, one mounted on the leg, one mounted on the foot, one mounted on the torso, one mounted on the forearm and one mounted on the upper arm. However it should be appreciated that the position and number of sensor elements 20 employed can vary depending on the type of motion to be analysed.

In essence, each sensor element 20 is capable of making detailed analysis of a number of aspects of motion of the body segment upon which it is mounted. Whilst the number and types of measurements that can be taken by each pressure sensor 20 is considerable in light of prior art systems, each pressure sensor is housed in a small and robust housing that can easily be worn on each body segment without limiting the movement of that body segment. This enables an individual to attach a number of sensors onto desired body segments and to wear such sensors under clothing and perform work related activities during the day, such that their continual motion including specific work related tasks, such as lifting can be monitored and analysed, without adversely affecting their movement.

The data from the sensor elements 20 is fed via a controller interface 31 to the controller 30. The controller 30 is worn externally of the subject's body for example, in a pocket or pouch located on the subject. The controller 30 may be in the form of a hand-held programmable device. Preferably, the controller 30 is in the form of a commercially available, pocket PC, PDA or a PDA-mobile telephone combination device. The controller 30 communicates with sensor elements 20 via a controller interface 31. The controller interface 31 interfaces to the controller 30 via a compact flash port. The controller interface 31 facilitates bi-directional communication with the sensor elements 20.

The controller 30 includes a display in the form of a liquid crystal display (LCD). Preferably, the LCD is implemented in the form of a touch-sensitive screen for enabling a workplace assessment officer or ergonomist to select, via appropriate icons on the screen, the motion analysis to be effected.

The controller interface 31 is in the form of a card that enables the controller 32 to interface with various peripheral devices but in particular the sensor elements 20.

The interface card may include a peripherals interface in the form of a QSPI interface for interfacing with the sensor packs 20. It is envisaged that the controller 30 can communicate with the/or each of the sensor elements 20 via a conventional wire link or via a wireless link. A wireless link will enable a

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greater amount of freedom of movement and ease of use to enable the subject or worker to perform the desired working tasks with minimum impedance.

A remote control interface is included for communicating with the remote control system 40 of the system 10. The remote control system 40 may include a PC located remotely from the worker or subject of interest, for example, the remote control system 40 may be a PC located and operated by an ergonomist or workplace safety officer situated in an area remote from the subject. In this regard, the sensed motion of the subject or worker can be monitored as they perform common tasks such as lifting objects, and the various measurements taken from the sensor elements 20 can be sent to a remote computer for analysis. This could occur in real-time such that a worker's motion can be monitored in order to ensure that the worker practises safe lifting and the like to detect or monitor cumulative loads before the onset of a problem, such as LBD, or may occur following completion of a task or at the end of a designated time period, such as at the end of each day.

The system of the present invention can be used to alert a worker, using an alarm, that their current motion is not optimal, upon detection of a specified criterion being exceeded during a performed task. Such a criterion can be calculated by applying common work place safety assessment tools, such as the NIOSH equation, or other similar measures previously mentioned using the collected data. As a result, the present system can be used in a number of applications, which have previously not been possible due to the fact that the subject was confined to laboratory spaces and dedicated laboratory equipment.

The present invention can easily be applied to monitoring manual lifting tasks and calculating the NIOSH Lifting Index (LI) for a worker or subject performing their daily work routine. As alluded to previously, the NIOSH equation uses 5 risk factors to calculate a recommended weight limit (RWL) for lifting. NIOSH starts with a 23 kg load constant that is reduced by a multiplier for each risk factor that has a value of less than 1. Multipliers are computed for the horizontal distance between the part lifted and the body, the start height, the vertical distance lifted, lift asymmetry, the quality of the hand object interface (coupling) and the frequency of lifting. The LI is computed by dividing the weight of the object to be lifted by the RWL. Lifting tasks that have

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a LI of less the 1 are considered acceptable. LI ratios of 1 will put a healthy worker at increased risk for LBD. The NIOSH equation also has provision to consider physiological factors such as energy expenditure, but until now how to incorporate such measures has been difficult to do. It can be immediately appreciated that this invention will allow measurement of physiological measures during lift, which is a significant advance to prior art.

The NIOSH analysis program of the present invention is comprised of two programming elements. The first programming element is deployed on the controller 30 such as a wearable PDA or similar portable device. The second programming element is deployed on a remote control system 40, such as a stand alone personal computer (PC). With regard to the first processing element, the sensor data can be processed by the PDA in real time, perform basic analyses and store the raw and processed data. With regard to the second processing element, the PC program can enable more detailed analyses of the lifting tasks, such as modeling and performing "what if" scenarios for work place redesign and other emerging applications once the data has been downloaded from the PDA. In this regard, such complex analyses can be done at a later time. In addition, the deployment of analysis software on a PC allows creation of a database of results so as to monitor progress and record keeping.

The purpose of the PDA analysis program is to convert raw sensor data obtained from the sensor elements 20 and calculate common parameters (both kinematic and spatiotemporal). The basic concept includes converting segmental tilt angles into segment coordinates that are then used to reconstruct an animated biomechanical stick figure using trigonometry or other mathematical conversion methods (spherical coordinates). The biomechanical segmental model depends on the number of sensor elements 20 that are attached to the subject. If seven sensor elements 20 are used it will create a seven-segment model. This allows accurate determination of user specified events during manual handling tasks such as when the worker picks up the object to be lifted and when the worker lets go at the destination. The determination of such events can then be used to calculate the initial height, the horizontal distance of the object from the worker, the distance of the lift, the quality of coupling, lift frequency and the asymmetry of the lift (amount of twisting of the torso), all of which are important factors to consider to calculate

the NIOSH lift index. The weight of the object to be lifted can also be obtained by an operator entering in such a value to the system, although a provision exists to determine the weight automatically using a small scale or knowledge of the goods being handled. From this the PDA is able to calculate the NIOSH lift index of a single lift, the cumulative load above and below the criterion LI of 1 from multiple lifts and provides auditory feedback or alarm if an LI of 1 is exceeded during an actual lift. In addition, the frequency and/or amplitude of the warning tone changes proportionally to increasing LI values (>1).

The PC program is organized into a series of panels from left to right. Data is firstly downloaded from the controller 30. The first panel is the anthropometry panel depicted in figure 2. When the program is executed the anthropometric data originally entered into the controller 30 is read. From this the X-Y coordinates and rotational angles of the torso and other segments are calculated. This data is then used to calculate the relevant parameters for the NIOSH equation.

Figure 3 shows the interactive frame-by-frame analysis screen. The screen is organized into a series of panels. Each panel has a specific function. Panel 2 indicates which file is being currently analyzed. Panel 3 shows the current stick figure representation of the sensor data during the lifting task, which is fully animated and controllable. The user can control the movement of the stick figure by pressing the appropriate frame-by frame button 4 or in normal time mode. As is shown, the controls are similar to VCR controls. The user animates the stick figure frame by frame and when a specific event (i.e. when the object is grabbed by the worker) is identified, the user will enter the appropriate data in 5. The program also allows for automatic event identification for many trials in which the worker lifts many objects during the course of the work episode. This will facilitate rapid analysis and automatically calculates lift frequency (lifts/minute). The user can also review identified events and if necessary corrections can be made. If no analogue signals were collected event identification 5 is done manually.

Once events are identified, the program extracts the data between events, normalizes it and calculates the relevant NIOSH equations, as well as,

estimated torque about lumbar levels L4/5. All data are saved for further presentation, or saved into a database.

Figure 4 is the parameter result screen of NIOSH analyzer. It displays the spatiotemporal parameters calculated for all strides of both limbs. The results can be saved as a spreadsheet file. The ability to obtain such important information via such a discrete and easy to use system as the present invention provides advantages not before realizable with prior art motion analysis systems.

In this regard, the present invention lends itself to a number of commercial uses. One obvious adaptation of the present invention is in monitoring and analysing worker motion as to train and inform workers about how to perform a specific task or tasks as safely as possible under varying task conditions. This can be done by providing instantaneous feedback or by visually comparing incorrect movements with that of correct movement. The present invention can also be adapted to be used by the ergonomist to design an optimum work area.

Other applications of the present invention may be in monitoring and analysing the motion of workers in order to allow for work place redesign so as to modify the task and the work place environment to minimize risk to the worker(s). This will have additional benefits because it will permit the minimization of work place injury (injury prevention) and increase production efficiency. It can be readily appreciated that the cost of preventing injury is of great benefit to the individual worker, society and the company. As mentioned, this can occur in real time situations, something which has not been possible with prior art systems.

Yet another example of the applications of the present invention can be appreciated to advance the field of workplace injury prevention. Many of the common tools used to assess the risk of work place injury are limited. This is because until now it was not possible to measure human motion under actual working conditions. The present invention will therefore permit important advances in the measurement of workplace injury risk, either by refinement of existing measures or the development of entirely new assessment tools. For

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instance the system will allow for tests to be developed that take into account specific of the individual worker, such as the worker's physiological capacity, age and gender as well as previous history of injury. Whilst the above applications are only examples of the commercial applications of the present invention, it is envisaged that there are many more examples that equally apply.

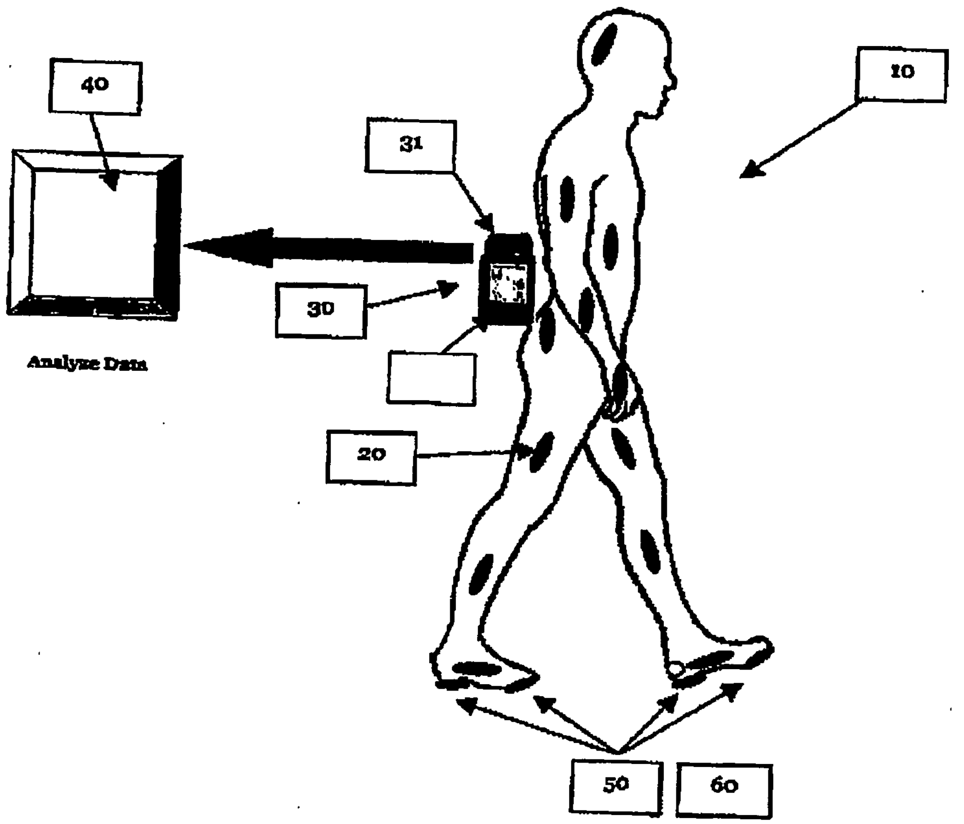

Figure 1

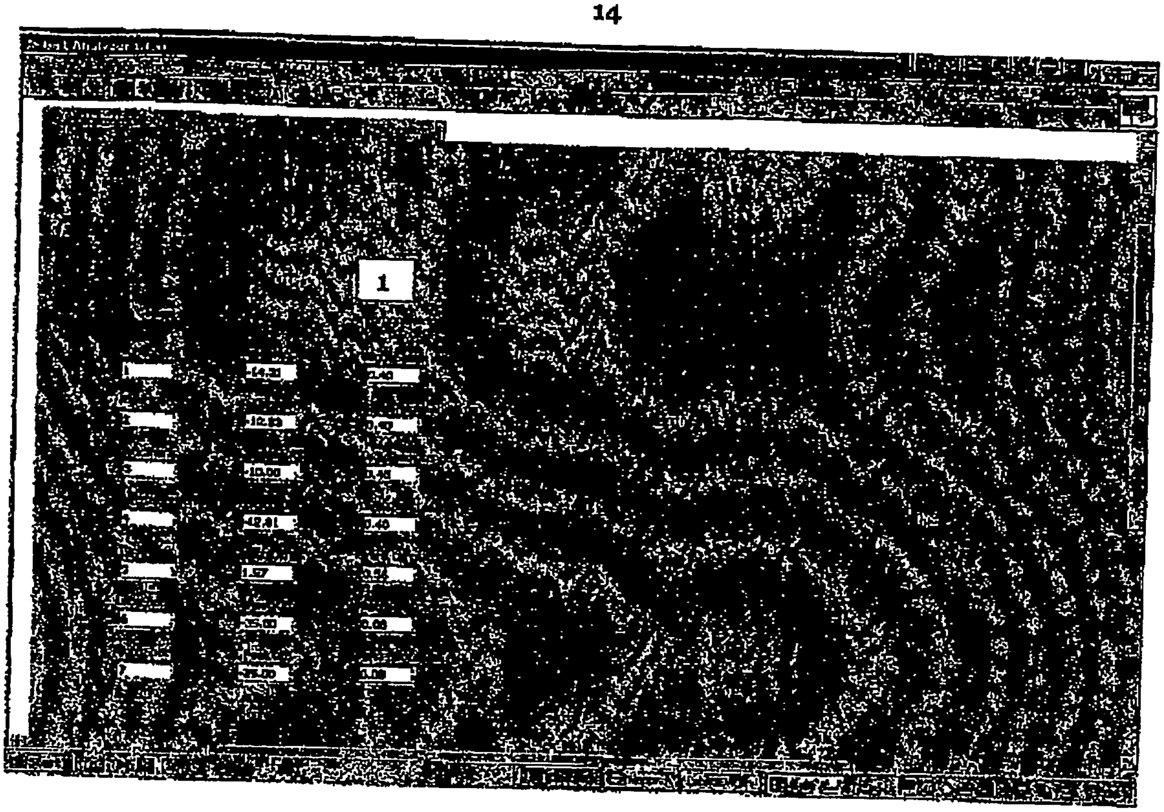

Figure 2

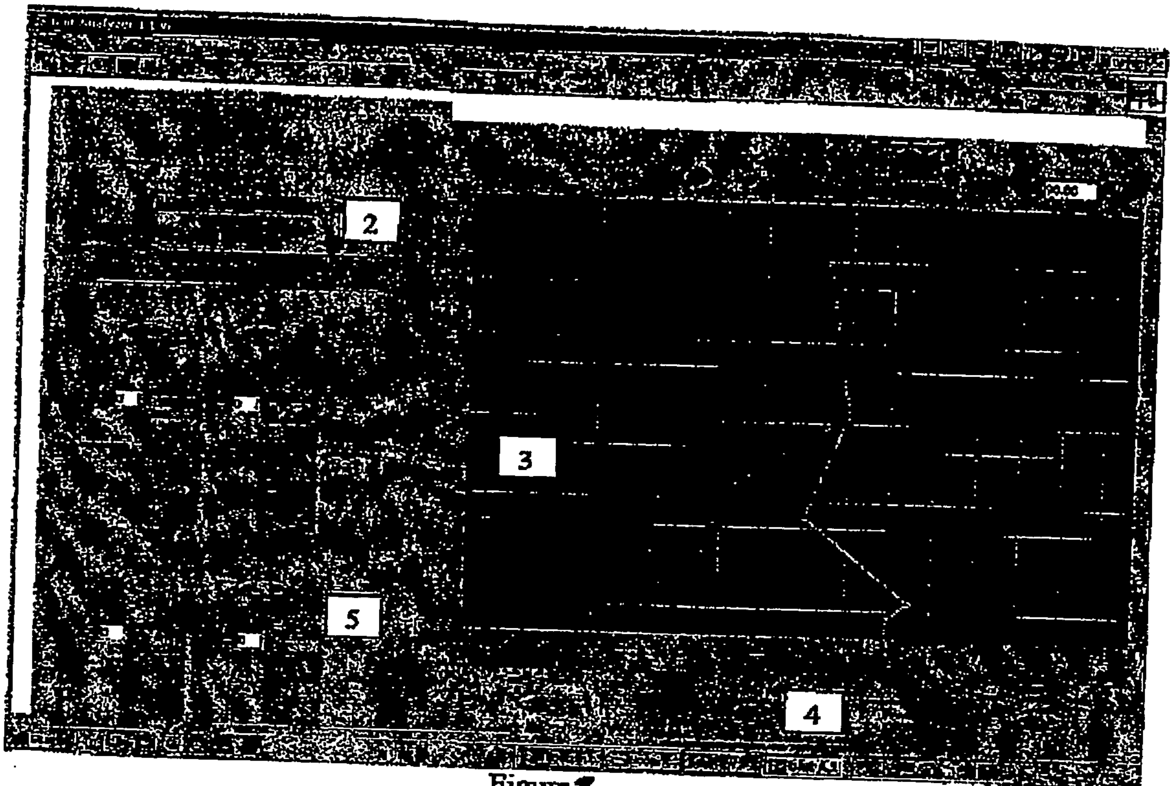

Figure 3

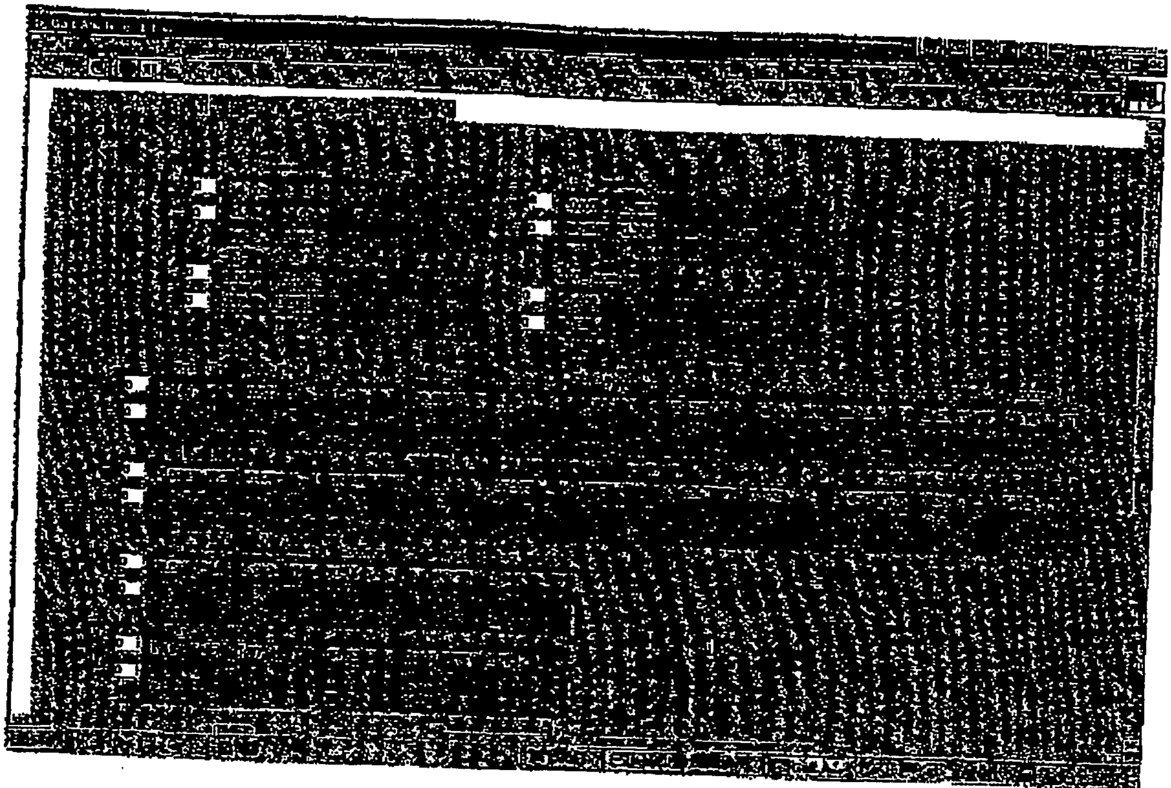

Figure 4